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1. Introduction

Across the lowlands of Northwestern Europe, point source discharges of nutrients have been greatly reduced since the early 1990ies (De Wit, 1999; EEA, 2005; Carstensen et al., 2006), and non-point sources now predominate the nutrient budgets of major rivers (EEA, 2005). Intensive agriculture is considered a major non-point source, although considerable regional differences exist in sensitivity due to soil characteristics and also in loading due to variable fertilisation intensity (e.g. Pieterse et al., 2003). For a further improvement of water quality of draining rivers and the receiving estuaries and coastal waters, the creation of buffer strips and retention basins and the re-establishment of previously common riparian wetlands are considered (Hoffmann and Baatrup-Pedersen, 2007). Verhoeven et al (2006), for example propose a starting hypothesis that 2-7% of a catchment should be wetland to realise measurable nutrient retention.We review literature on nitrogen retention along streams and rivers of NW Europe from the narrow first order upper headwaters down to the main channels flowing through wide lowland floodplains. Our aim is to achieve rules of thumb for net retention rates as a function of loading and due to all major pathways involved. We need these retention rates to apply in a spatially explicit river drainage network model that will contain riparian retention as a management measure. We contrast here the upper and lower catchment riparian zones a priori, because their geography is widely different (e.g. Morisawa,1985). In reality, however, a continuous gradient exists along the length of a river when it gradually increases in discharge volume, channel and floodplain width (Petts and Foster, 1985).

Earlier raster-based catchment nutrient models (e.g. Weller et al., 1998; De Wit, 1999) have modelled nutrient retention in the catchment simply as a proportion of quantity applied to the land drained by the river network, and some added a percentage for the stream channel bed (Pieterse et al., 2003). Recently, several European studies have quantified nitrogen budgets and fluxes across riparian zones (e.g. Sabater et al., 2003), hence it seems worthwile to incorporate such estimates explicitly in our models and allow the evaluation of alternative options of positioning wetlands and riparian buffers along a river network. We compiled these data and expressed them as (a) % reduction of N concentration per meter of buffer strip perpendicular to the stream, or (b) % of annual load flowing across a river floodplain. Published data on floodplain retention were particularly scarce.

2. Results and discussion

For buffer strips, we could collect data from 7 studies (Clement et al., 2003; Hefting, 2003; Hoffman et al., 2006; Pieterse et al., 2005; Sabater et al., 2003; Dhondt et al., 2006; Van Beek et al., 2007). Several of these contained data on a number of stream bank buffer strips. We found that distance-scaled retention did not correlate significantly with nitrate concentration of the groundwater (Figure 2.1a). The latter is generally the main contributor of nitrogen. This is not surprising since loading rates may vary substantially with groundwater flow rates, and since the local geomorphological setting, standing vegetation, soil conditions (pH, organic matter content) and site management may also be important modulators of retention (e.g. Sabater et al., 2003). However, we did find a relation with the width of the strip. Distance-scaled retention decreased with the width of the buffer strip, and the pattern may suggest some nonlinearity (Figure 2.1b), with declining retention for buffer strip widths beyond 15 m. A mean retention rate was 7.5 ± 2.0 % m^{-1} (n=12) for strips of on average 16 m wide. Loads of these wetlands were not always reported, a.o. because of difficulties with estimating groundwater in- or throughflow, and range widely (500 ±140 kg ha^{-1} y^{-1}, n=6 only).

In downstream floodplains, nutrient retention from the flood water would only occur during flooding. It depends critically on inundation duration, but also on the flow rate of the water, the season and on the type of vegetation present (cf Olde Venterink et al., 2006). Unfortunately, we have only 2 studies with quantitative estimates. Retention rates range widely between 70 and 200 kg N ha^{-1} y^{-1}, corresponding to 3-71% of highly variable loads (Olde-Venterink et al., 2006; Hoffmann and Baattrup-Pedersen, 2007). In many rivers of NW Europe, dissolved nitrate is now the predominant form of nitrogen transported (Olde-Venterink et al., 2003; Soetaert et al., 2006; Radach and Pätsch, 2007), and sedimentation as well as denitrification rates are low in the flowing water, particularly in the downstream floodplains where large volumes of water pass during flooding. Only when inundation is prolonged, such as in backwaters, along smaller branches, or during slack tides in the tidal region, nitrogen retention can become substantial. Sollie (2007) reported denitrification rates for permanently inundated littoral zones of shallow Dutch lakes in the range of 4-146 kg N ha^{-1} y^{-1}, strongly depending on water depth, with an optimum around 30-40 cm depth. She also reported net sediment accumulation rates of 160-400 kg N ha^{-1} y^{-1}, mainly due to burial of organic matter. Together, median nitrogen removal due to denitrification and sediment accumulation in permanently indundated shallow littorals would be in the order of 250 kg N ha^{-1} y^{-1}, a bit beyond the range reported for floodplains (cf Olde-Venterink et al., 2006), and suggest a considerable potential for flood retention basins. The pattern for N contrasts with that of P, which is generally bound to particulate matter and will be subject to substantial sedimentation (Olde-Venterink et al., 2003; 2006).

The recently implemented flood control areas along the tidal Scheldt may well offer considerable retention because water enters each tide, and the hydrograph is well-controlled (Cox et al., 2006). Here, The nitrogen retention capacity is estimated at 1 kg ha^{-1} $tide^{-1}$ (Tom Maris, pers. comm.), which would roughly be some 700 kg ha^{-1} y^{-1} , considerably higher than the estimates for floodplains of small Danish and large Dutch rivers published so far. Figures

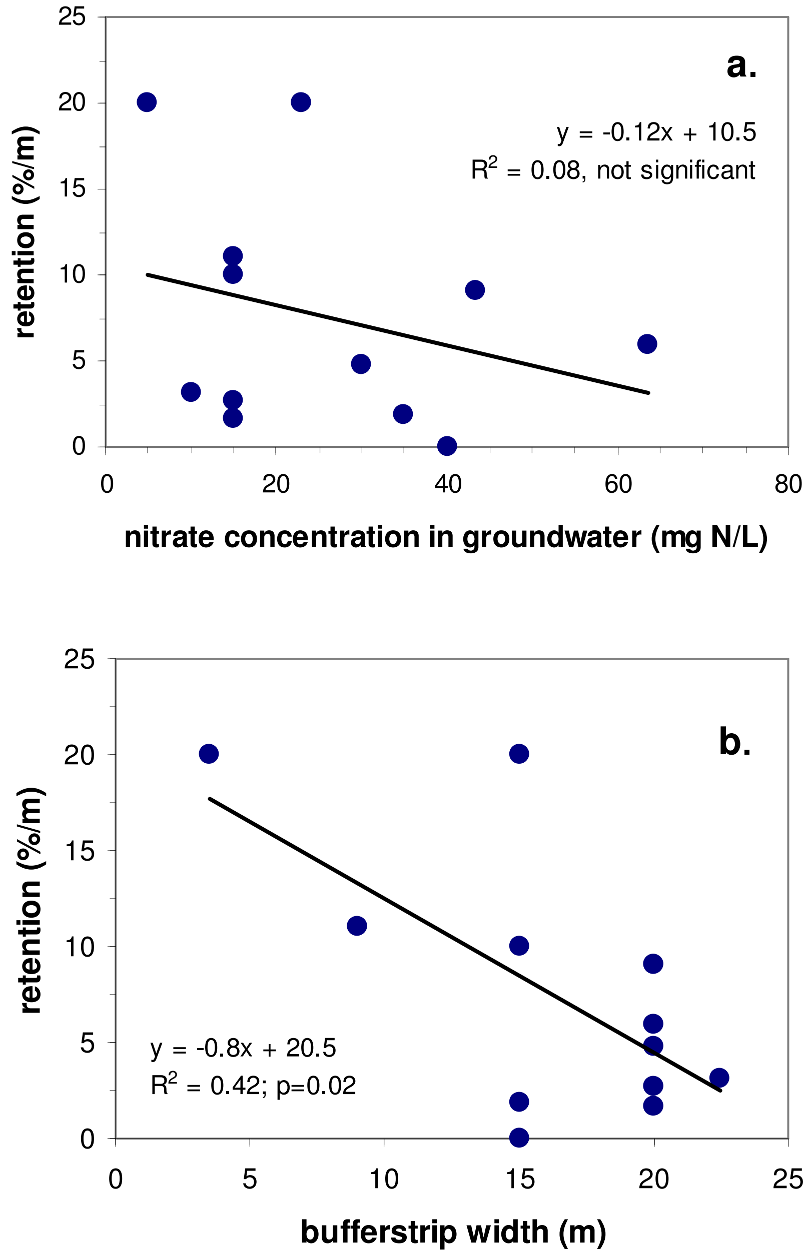

Figure 2.1. Proportional Nitrogen retention (% per meter) in buffer strips separating intensively fertilized agricultural land and lower order streams as a function of groundwater Nitrate concentration and width of the buffer strip deployed.

3. Conclusion: rule-of-thumb figures

For riparian buffer strips in lower order streams draining intensively fertilised agricultural fields we suggest that a nitrogen retention rate of 7.5 ± 2.0 % m^{-1} (n=12) would be a reasonable estimate. In general these strips would form 15 m wide corridors between fields and streams.

For temporarily inundated floodplains, the available literature is probably too limited to offer a rule-of-thumb with any confidence, also because nitrogen is presently mainly available in dissolved form as nitrate and its retention is very limited during periods of high flow.

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